Ergonomic design intervention in a coating production area

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ABSTRACT: The aim of this study is to redesign two workstations in a PVD coating production area, considering productivity and ergonomic aspects. Through the elimination of wastes such as unnecessary movements and transportations and by reducing the awkward postures as arm flexion larger than 45º, the productivity in the loading and unloading workstations increased 9% and 5%, respectively, and the ergonomic risk was improved from medium to acceptable. RULA was the chosen method to evaluate the ergonomic situation and anthropometric studies were performed to find the ideal ergonomic solution. This study shows the importance to consider ergonomic conditions when designing or redesigning a workstation in order to get effective productivity improvements.

1 INTRODUCTION

Due to demographic variation, fewer young workers are available and the overall number of workers will decrease. The length of absenteeism, especially due to musculoskeletal disorders (MSDs), increases with age (Müglich et al., 2015).

Work-related musculoskeletal disorders (WMSDs) cause muscles, tendons and nerves at the joint of the neck, shoulder, elbow, wrist, finger, back, leg, etc. to be stressed and traumatised due to excessive or repetitive exertive force, awkward body posture, less resting time, cold working environment, vibration and so on (Cheol-Min et al., 2011).

With regard to Europe, the data emerging from the 5th European Survey on Working Conditions (ESWC) in 2010 (Eurofund, 2012) reports that 33% of all European workers spend at least 25% of their working time performing manual load handling. About 47% of the labour force is exposed to awkward postures during at least 25% of their working time, and over 33% of European workers perform repetitive movements of the upper limbs for almost their entire working time.

Moreover, when considering WMSDs as an occupational disease, upper limb MSDs such as hand-arm tendonitis, epicondylitis and carpal tunnel syndrome represent more than 55% of all occupational claims reported in the different insurance systems (Eurostat, 2010). It was reported by Muggleton et al. (1999) that rotator cuff tendonitis is closely associated with the upper arm abduction and forward flexion. It has been shown that, with arms raised or abducted, the blood vessels supplying the tendons of the supraspinatus muscles were compressed (Grieco et al., 1998), thus altering blood circulation. Such postures render the shoulder-arm system vulnerable to MSDs.

An ergonomic approach to the design of an industrial workstation attempts to achieve an appropriate balance between the worker capabilities and the work requirements to “optimize” both worker productivity and the total system productivity, as well as to provide worker physical and mental well-being, job satisfaction and safety. In a real world design situation, the implementation of the recommendations or guidelines needs the matching of the population anthropometry with the various components of the workstation (Das and Sengupta, 1996).

Often, in industry, the workstation is designed in an arbitrary manner, giving little consideration to the anthropometric measurements of the potential user. The situation is aggravated by the non-availability of usable design parameters or dimensions (Das and Grady, 1983a; Das, 1987). The physical dimensions in the design of an industrial workstation are of major importance from the viewpoint of production efficiency, and operator physical and mental well-being. Small changes in workstation dimensions can have a considerable impact on worker productivity, and occupational health and safety. Inadequate posture from an improperly designed workstation causes static muscle efforts, eventually resulting in acute localized muscle fatigue, and consequently in decreased performance and productivity, and enhanced possibility of operator related health hazards (Corlett et al., 1982). The aim of this work is to answer the research question: "How can be improved the workstation design of loading and unloading processes of a PVD coat production area, considering ergonomic aspects and productivity?" This case study takes place in a PVD coating production area, where workers' complaints due to shoulder pains were rising considerably. These com-plaints come mainly from the processes of loading and unloading pieces from the suspension, before and after the product entering the PVD machine, respectively. This is a repetitive job and involves several awkward postures such as: flexion of the arms above 45º (from now on "arms up"), trunk flexion, and move manually heavy suspensions. Being such a specific case study, an identical case was not found in the literature.

The paper is structured as follows: the section 2 explains the methods used to evaluate the initial situation followed by the methods used to redesign the workstation; section 3 provides a discussion of the main results and section 4 points out some conclusions and recommendations.

2 METHODS

The methodology used was the case study. According to Yin (2003), a case study should be defined "…as a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context." Following this key idea, the case study, as a research methodology, helps to understand, explore or describe a given system/problem in which several factors are simultaneously involved, in a real context.

The first step was the election of a multifunctional team, including operators, to analyze the process and measure the initial situation in terms of ergonomic conditions and productivity. Then this team suggested some workstation modifications in order to improve ergonomic conditions, reduce wastes (e.g., unnecessary movements and transportations) and increase productivity. After the implementation of the suggested improvements, the team measured the productivity and the ergonomic conditions and compared them with the base scenario.

Despite the good results in the first redesign intervention, they weren't enough to achieve acceptable ergonomic risk. It was necessary to intervene again, breaking some paradigms and designing the "ideal" workstation that suited any worker with no wastes in terms of movements and transportations.

2.1 *Measurement tools*

RULA (Rapid Upper Limb Assessment) was the tool used to assess the postures, movements and forces exerted by the worker while performing the job, because it is especially useful for scenarios in which work-related upper limb disorders are reported.

The higher the RULA score - varies from 1 to 7, defining the action level to be taken- the higher risk associated and the greater the urgency to carry out a more detailed study and introduce modifications to the job/workstation. The scores 1 and 2 (action level 1) indicates that the posture is acceptable if it is not maintained or repeated for long periods of time. The scores 3 and 4 (action level 2) indicates that further investigation is needed. The scores 5 and 6 (action level 3) indicates that changes are required soon. The score 7 or more indicates that changes are required immediately.

The knowledge of the team in lean production was important in the achievement of the better solution in terms of productivity. The key idea of lean is "doing more with less", where less means less space, less inventory, fewer resources, among others (Womack et al. 1990).

Productivity was calculated using the number of pieces produced per hour (throughput or production rate) because it is the measure typically used in this production area, being also one of the most well-known measures of productivity in industry.

2.2 *Workstation Redesign*

The biggest team concern was the manually suspension movement between the carpet and the table due to the effort and the awkward posture necessary to perform this task and because it involves two kind of wastes: movement and transportation. Waste means, in a lean terminology, something that doesn't add value to the product, this means something that the client doesn't pay for (Womack et al., 1990). The other concern was the elevation of the arms considering the ergonomic aspects and the tiredeness accused by operators, also contributing to a loss in productivity (Figure 1).

Figure 1– Unloading workstation before improvements.

The founded solutions for these detected problems were the following:

- Construction of a structure to place the lighter suspensions horizontally and reduce the time of arms up.
- Integration of a structure with a rotating base at the end of the machine carpet to load and unload pieces directly and eliminate the necessity of take and move manually the suspension between the carpet and the table (Figure 2).
- The new structure allows a manual adjustement of the work plan to reduce the arms flexion (Figure 2).

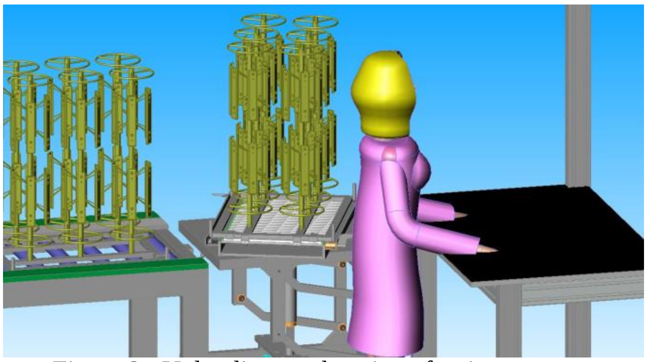

Figure 2– Unloading workstation after improvements

The Figure 3 depicts the worker in the unloading workstation after the implementation of these improvements.

Figure 3– Unloading workstation after improvements

The implementation of an ergonomic solution was also necessary for the container changing process.

The Figure 4 depicts the awkward posture adopted in this process. The container has an average weight of 6kg but could rise to 9kg maximum.

The solution was the implementation of a lift car, similar to the one in Figure 5.

Figure 4– Container changing

Figure 5 – Lift Car

2.2.1 Anthropometrics studies

Anthropometric studies were used to redesign the structure and take into account the adjustment of the workstation to the body characteristics of the operators, e.g., their stature.

In order to adjust the work plan, and eliminate the necessity of arms up above 45º, it was provided an automatism to up and down the suspension, based on the standard cycle time for producing each reference.

It was also provided an option to change from automatic to manual, when worker have difficulties to accomplish cycle time, for some reason.

The existing paradigm of the grids suspensions in rectangular shape was overcome and a round shape was elected (Figure 6). The advantage of this change is the reduction of the distance between operator, suspension and table, resulting in less movements such as trunk rotation.

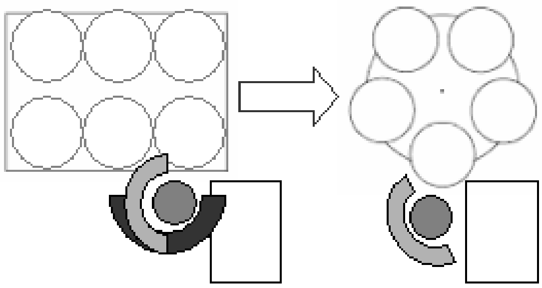

Figure 6–Suspension grid shape: rectangular vs round.

The vertical amplitude of the structure was calculated based on the anthropometric database of the Portuguese population (Barroso et al., 2005): the maximum limit was calculated using the measure of floor-to-elbow of the man’s 95 percentile (1159 mm) and the minimum limit was calculated by using the measure of floor-to-elbow of the woman’s 5 percentile (914 mm). This structure also includes a rotary base to bring the suspension closer to the worker.

In Figure 7 it is possible to see that the proposed solution allows different types of workers to perform their job without elevating their arms above 20º.

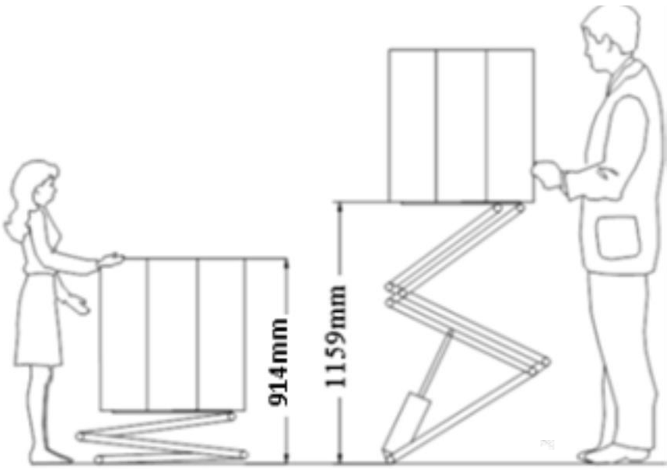

Figure 7–Structure automatized to elevating the suspensions

Like any investment, the costs component is very important in the decision of forward or not with the project. The estimated cost to implement this solution is about 2700€.

3 RESULTS

Productivity was calculated for 23 references which represent 80% of the total quantity produced in this production area.

Table 1 shows how much productivity increased: about 9% in the load operation and 5% in the unloading operation. This difference is due to the bigger distance between the table and the carpet in the loading workstation than the same distance in the unloading workstation.

Table 1. Productivity (throughput in pieces/hour).

Workstation	Initial Situation	After Improvements
Loading	800	872
Unloading	900	945

According to RULA method (McAtamney & Corlett, 1993), the most inappropriate postures before the improvements were moving the suspension and container changing (scored with 6).

The moving suspension task was eliminated and the RULA score to perform the task of changing container was reduced from 6 to 4 by the implementation of the lift car.

Table 2 and Table 3 depicts the RULA score and the percentage of time spent in each posture in the initial situation and after improvements at the loading and unloading workstation, respectively. The time spent in a position implying arms up was reduced from 29% to 24% through the implementation of the horizontal structure and by lowering the work plan. The ideal posture of the arms (arms between -20º to 20º) is achieved when the worker uses the horizontal structure (14% of the time).

Table 2. RULA score and percentage of time spent in each posture (loading workstation) before and after the ergonomic improvements.

Loading Workstation	**Initial Situation**		**After Improvements**	
	RULA	Time	RULA	Time
Arms Flexion -20º to 20º	-	-	3	14%
Arms Flexion 20º to 45º	4	56%	4	52%
Arms Up (>45º)	5	29%	5	24%
Move Suspension	6	5%	-	-
Container Changing	6	10%	4	10%

Table 3. RULA score and percentage of time spent in each posture (unloading workstation) before and after the ergonomic improvements.

Unloading Workstation	**Initial Situation**		**After Improvements**	
	RULA	Time	RULA	Time
Arms Extension/Flexion -20º to 20º	-	-	3	14%
Arms Flexion 20º to 45º	4	57%	4	51%
Arms Up (>45º)	5	30%	5	25%
Move Suspension	6	3%	-	-
Container Changing	6	10%	4	10%

In the initial situation, the weighted average was 5 for both workstations indicating that investigation and changes are required soon.

After the workstation improvements, the action level decreased from 3 to 2 means that more changes may be needed to reach the negligible level (action level 1). For this reason, another workstation redesign was performed, taking into account the anthropometric aspects and the elimination of awkward postures, i.e. trunk flexion and arms up. The team estimated that with this redesign the worker would perform 90% of their work with arms extension/flexion between –20º to 20º (Table 4 and Table 5).

Table 4. RULA score and percentage of time spent in each posture (loading workstation) before and after the final redesign implementation.

Loading Workstation	**Initial Situation**		**After Redesign***	
	RULA	Time	RULA	Time
Arms Extension/Flexion -20º to 20º	-	-	3	90%
Arms Flexion 20º to 45º	4	56%	-	-
Arms Up (>45º)	5	29%	-	-
Move Suspension	6	5%	-	-
Container Changing	6	10%	4	10%

*Estimated values

Table 5. RULA score and percentage of time spent in each posture (loading workstation) before and after the final redesign implementation.

Unloading Workstation	**Initial Situation**		**After Redesign***	
	RULA	Time	RULA	Time
Arms Extension/Flexion -20º to 20º	-	-	3	90%
Arms Flexion 20º to 45º	4	57%	-	-
Arms Up (>45º)	5	30%	-	-
Move Suspension	6	3%	-	-
Container Changing	6	10%	4	10%

*Estimated values

After the new workstation redesign, the ergonomic risk could be reduced from the level 4 to the level 3. Although the good results, they are not enough to reach the risk level 1 - acceptable risk. The reason is the repetitiveness of the tasks. A possible solution could involve the enlargement of the job.

Table 6 summarizes the RULA score from the initial situation to the final redesign in both workstations.

Table 6. RULA score summarize.

Workstation	**Initial Situation**	**After Improvements**	**After Redesign***
Loading	5	4	3
Unloading	5	4	3

*Estimated values

Despite the demonstration made by the team of the working conditions improvements after the redesign implementation, the company decided not to proceed with the redesign due to the high investment value.

4 CONCLUSIONS

Due to the hard competition, demanding customers and competitive world that companies face, nowadays, it is very important to consider productivity measures while implementing improvements in the shop-floor. On the other hand, jobs are more repetitive leading to musculoskeletal disorders, increasing absenteeism and reducing productivity.

The conclusions of this study are limited to this case, but the authors believe that is possible to consider both aspects, ergonomic conditions and productivity, during improvements implementation.

As illustrated in the section of results, the improvements reached in the ergonomic conditions can contribute very positively for productivity increases.

The authors’ opinion is that ergonomic conditions must be considered when designing/redesigning a workstation in order to get effective productivity improvements. Actually, in general, it is still difficult to implement ergonomic aspects in companies because some decision-makers do not view ergonomics as an investment, but rather as an expense.

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